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"The Action of X-ray on Basal Metabolism"

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The Action of X-ray on Basal Metabolism

The very marked changes that occur in the body after the absorption of radiant energy (light, X-rays, radium rays) lead one to suppose that these changes may be accompanied by changes in basal metabolism. A review of the literature shows that very little experimental work has been done on this subject. With X-rays there are no experiments at all showing the result of exposure on the metabolism of normal animals. All the published data are concerned with the effect of X-rays on the metabolism of patients with either cancer or leukemia.

Experiments were therefore undertaken to find the effect of X-ray exposure on the basal metabolism of birds. These experiments gave very striking and consistent results, which are reported in the second part of this paper. The first part gives a review of the literature on the subject.

I am indebted to Dr. J. H. Clark and Dr. A. L. Meyer for the interest they have taken in my work and for their kind assistance in accomplishing it.

Baltimore, May 15, 1922

Dr. A. L. de Barros Barreto

THE ACTION OF X-RAYS ON BASAL METABOLISM

PART I -- A Review of the Literature on the Subject.

VISIBLE LIGHT

Moleschott -- 1855 -- was the first to carry out experimental work on the effect of physical agents on metabolism. From a large number of experiments on frogs he concludes:

a - these animals expire under similar temperature conditions, $\frac{1}{12}$ to $\frac{1}{4}$ more carbon dioxide (CO_2) in the light (daylight) than in the dark;

b - the production of carbon dioxide is in proportion to the intensity of the light, i.e. the greater the intensity of the light, the greater the quantity of carbon dioxide produced;

c - this action of the light is effected not only through the eye but also through the skin.

Martin and Friedenwald -- 1889 -- with the purpose of establishing the action of daylight on the carbon dioxide production, carried out a series of twenty-six experiments on frogs of the species Rana catabiana, deprived of their cerebral hemispheres. Thirteen of these animals were put in the light and thirteen in

in the dark. In order to determine whether, in frogs from which the cerebral hemispheres were removed, light acts only through the eye or whether it also acts partly through the skin, the eyeballs were also removed.

They conclude:

a - in frogs deprived of their cerebral hemispheres a greater quantity of carbon dioxide is given off in the light than in the dark;

b - the influence of light in producing greater oxidations in normal frogs is simply reflex and not due to greater bodily activity brought about by psychical conditions dependent on light;

c - the cerebral hemispheres do not take any direct part in regulating the oxidations of the frog's body;

d - this reflex action of the light, though mainly effected through the eye, is also produced partly through the skin.

ULTRA VIOLET LIGHT

There is considerable evidence for believing that the absorption of ultra violet light in the body acts as a stimulus to calcium and phosphorus metabolism.

A number of clinical papers on the treatment of rickets (Huldschinsky, 1920; Erlacher, 1921; Hess and Unger, 1921) have reported that, after exposure to ultra violet light, the recalcification of bones proceeds at an accelerated rate. Evidence for this was furnished by radiographs.

More recently it has been demonstrated beyond doubt that rats fed on diet, known to produce rickets, fail to develop the disease if they are exposed daily to sunlight or to the quartz mercury arc (Hess, 1921; Shipley, 1921; Powers, 1922).

A study of the chemical changes in the blood under sunlight treatment for rickets by Hess and Gutman (1921) showed that the inorganic phosphorus of the serum, which is reduced in children suffering from rickets, comes back to normal under sunlight treatment. Lasch (1921) observed the effect of ultraviolet light on the calcium and phosphorus metabolism in rickets and craniotabes cases in prematurely-born children two to three months old. Before the treatment both phosphorus and calcium metabolism were below normal. After three treatments with ultra violet light a marked retention of calcium and phosphorus was noted and the children were clinically cured. One month after the treatment the retention of calcium and phosphorus was still above normal. It is quite certain, therefore, that the absorption of ultra violet light affects the calcium

and phosphorus metabolism of the body and stimulates the deposition of inorganic salts.

ROENTGEN RAYS

Baermann and Linser -- 1904 -- studying the urine analysis of patients exposed to the action of X-rays, found a rise in the total nitrogen after the radiation.

Heile -- 1904 -- observes an increase in both uric acid and purin bases in three cases of leukemia treated by roentgen-therapy.

Lossen and Moravitz -- 1905 -- in one case of myelogenous leukemia found that the uric acid elimination, having been high during the exposure to X-rays, returned to normal coincidently with the leukocyte count. In another case of the same disease the uric acid remained high even after irradiation had produced an actual leukopenia.

Musser and Edsall -- 1905 -- in one case of leukemia in which the X-ray had no beneficial effect clinically, it likewise had little or no effect on the nitrogenous metabolism. In another case of the same disease in which there was a marked reduction in the number of white cells and clinical improvement, there was a definite increase in uric acid and purin base output, a very striking loss of nitrogen, and an increased elimination of phosphorus.

<u>Williams</u> -- 1906 -- noted the action of X-rays upon uric acid excretion in a pathological condition; myelogenous leukemia. The patient was placed on a fixed diet containing 25 grams of nitrogen per diem; the total nitrogen in the feces and urine was estimated and also the uric acid present in the urine. The investigation resolved itself into an estimation of the average nitrogenous excretion of the patient upon his standard diet, before and after exposure to the X-rays. The average daily excretion of uric acid for five days preceding the application of the rays was .4738 gram; irradiation was then practiced for ten minutes each day, arrangements being made that the exposures, which were to be given on each successive day, should be given under exactly the same conditions.

The quantity of uric acid excreted during the period of irradiation was distinctly above the normal, as is seen from the following figures:

Day	Quantity of Uric Acid
1	.5100
2	.6682
3	.5610
4	.9391
5	1.0220
6	.9513

Average excretion per diem during period of irradiation being rather over .7752 gram per diem against .4738 gram before treatment.

A further interesting feature is that on two days the total nitrogen output exceeded the intake. On the fourth day of exposure to the X-rays, owing to an attack of vomiting, the total nitrogen intake was only 13.28 grams, while the output in urine and feces was 14.92 grams. On the fifth day, again, the nitrogen intake was 16.01 grams, the output being 17.87 grams.

The following table gives the figures for the different days of treatment:

Day	Nitrogen Intake	Nitrogen in Urine	Nitrogen in Feces	Total Nitrogen Output
1	24.27	14.27	3.60	17.87
2	20.24	16.60	2.34	18.94
3	21.13	19.18	1.60	20.78
4	13.28	13.25	1.67	14.92
5	16.01	16.98	.89	17.87
6	18.20	15.69	1.32	17.01

Blood counts made daily during this time showed a marked rise in the number of leukocytes on the fifth day.

On referring to the case-books of the Royal Infirmary, Liverpool, where the observations were carried out, Williams found that of seven cases also treated by X-rays, an initial leukocytosis occurred in five, all within eight days of the first exposure. A rise of temperature at night was also observed while exposures to the X-rays were being given.

Koniger -- 1906 -- in seven cases of chronic myelogenous leukemia found a marked change in the uric acid elimination following exposure to roentgen rays, this consisting, first, in a marked increase and later in a reduction to a normal figure as the blood picture approached an aleukemic condition.

Benjamin and von Reuss -- 1906 -- in a normal dog, after a single very intense exposure to X-rays, observed a slight rise in the total nitrogen, on a fixed intake, lasting several days; and after the second day an increase in phosphorus.

Linser and Sick -- 1906-1907 -- found an increase in uric acid and purin bases and a decrease in the leukocytes of the blood after radiation by X-rays.

Cavina -- 1913 -- in a case of lymphatic leukemia, observed no increase either in uric acid or total nitrogen while the patient was being treated with the X-rays.

Murphy, Means and Aub -- 1917 -- say that an intensive treatment with roentgen rays, in a case of chronic lymphatic leukemia, caused a drop in the leukocyte count but did not appreciably affect the level of his metabolism. After treatment

with radium a further and very marked fall occurred in the leukocyte count and at the same time a slight fall occurred in the basal metabolism.

De Niord, Schreiner and de Niord -- 1920 -- studied a group of forty-one patients of different types of cancer (epithelioma, carcinoma, lymphosarcoma, etc.) before and after exposure to X-rays for the purpose of seeing if there was any change in their metabolism. The studies were made immediately before roentgen ray exposure, half an hour later, and on the next day, approximately twenty-four hours afterward. The following factors were estimated in milligrams per 100 c.c. of blood in each instance: Urea, creatinine, uric acid, chlorides, cholesterol, fatty acids, total fats, sugar, diastatic activity, plasma and corpuscle percentage.

Several control studies were made on normal people subjected to the same doses of X-rays, and also on cancer patients without roentgen ray exposure. They arrived at the following conclusions:

a - urea, urea nitrogen and creatinine show nothing characteristic of the cancer patient;

b - the moderate uric acidemia which exists for a short period of time after exposure to X-rays is the result of

nuclear degeneration, but is not especially characteristic of malignancy;

c - the sodium chloride content of cancer patients is altered neither by the presence of the tumor nor by the exposure to X-rays;

d - cholesterol, fatty acids and total fats are generally increased in cases of malignancy; cholesterol is increased in the blood but this is not in proportion to the duration of exposure to X-ray; fatty acids and total fats are reduced by the roentgen rays;

e - X-rays activate the diastase for a short period of time to a greater activity than normal;

f - the plasma and corpuscle percentages were unaltered by the effect of X-rays.

RADIUM

Fofanoff -- 1910 -- studied the action of radium on rabbits, in which he produced artificial tophi by injecting mono-sodium urate. The animals were then treated with emanation, either in the "emanatorium" or by injection of emanation in solution. The tophi and adjacent tissue were then excised and microscopically examined.

As a result of the action of the emanation, this observer records a diminution in the amount of leukocyte infiltration in the tissue surrounding the tophi, and further comes to the conclusion that the emanation has a solvent action upon the monosodium urate itself.

Olszewski -- 1910 -- observes that the inhalation of radium emanation in an "emanatorium" has no influence upon the secretion of gastric juice.

Gudzent -- 1910 -- says monosodium urate is converted by a disintegration product of the emanation (namely radium D) into more soluble bodies, which are eventually broken down into ammonia and carbon dioxide. Gouty patients under "emanatorium" treatment showed a marked diminution of the uric acid content of the blood. In two cases where before treatment the uric acid was 10 milligrams per 100 c.c. of blood serum, after treatment the figure had sunk to 6 milligrams per 100 c.c.

Kikkoji -- 1911 -- studying patients undergoing the "emanation" treatment, found that in three patients the oxygen inspired and the carbon dioxide expired were increased in two cases and unaltered in one.

Mesernitzki -- 1911 - says that radium emanation produces vertigo, headache, faintness, weakness and pains in the

joints, and among its objective results are emaciation, albuminuria and hemorrhages, symptoms probably due to the action of the alpha rays.

Kikkoji -- 1911 -- found a significant increase in the basal metabolism in a case of chronic arthritis and in a normal man, but found no effect in a second case of chronic arthritis. The two cases that showed a rise in basal metabolism likewise showed an increase in total nitrogen and uric acid elimination.

Knaffl-Lenz and Weichowski -- 1912 -- deny the influence of radium upon the solubility of uric acid, though they find that the emanation brings about a rise in the elimination of uric acid, not only in gouty patients but also in normal individuals.

Benczur and Fuchs -- 1912-1913 -- found that the ingestion of one hundred times the usual therapeutic dose of radium emanation causes an increase in respiratory metabolism of 17 per cent.

Noorden and Falta -- 1913 -- say that the radium emanations have a marked effect, causing an increase in all times of metabolism.

Theis and Bagg -- 1920 -- studied the effect of intravenous injections of the active deposit of radium on metabolism in the dog. They used solutions of sodium chloride containing active deposit from radium emanation. After a control period of five days

the following doses were injected:

DOG I	DOG II
1 - 95 millicuries	1 - 120 millicuries
28 days	19 days
2 - 30 millicuries	2 - 17.3 millicuries
10 days	9 days
3 - 42 millicuries	3 - 54.7 millicuries
23 days	14 days
4 - 64 millicuries	4 - 146.4 millicuries
Vomiting, refusal of food; anesthetized, killed.	4 days
	Refusal of food, severe diarrhea; anesthetized, killed.

Urine and feces were collected and analyses were made for : Nitrogen, urea, ammonia, creatinine, uric acid and phosphates. Albumin, sugar and creatinine were tested for frequently with negative results. They conclude: "In every instance in both experiments the injection of active deposit was followed by an increased output of nitrogen, reaching the maximum figure on the second day after the treatment. The first creatinine increase is noted after the second injection, and its highest values are noted on the days after the treatment when the nitrogen is also high. Uric acid showed a marked increase both absolutely and relatively, following the injection of radioactive deposit. The physiological effects are presumably due to the alpha radiation.

Redfield and Bright -- 1922 -- carried out a series of experiments to test the effect of the beta rays of radium on those metabolic processes which result in the production of carbon dioxide, and to demonstrate whether any correlation exists between alterations produced in these activities and the ability of the protoplasm to take part in cell division and growth. They have made use of radish seeds and measured the carbon dioxide given off before germination has had time to take place. The radiated seeds were exposed to radium emanation through a glass tube and control experiments were made with unradiated seeds. They found that the rate of carbon dioxide production in radiated seeds was invariably greater than in the unradiated controls, while the germination of the radiated was retarded to a marked degree. They conclude, therefore, that no direct relation exists in this case between the rate of carbon dioxide production and the rate of growth. Radiations have a specific action on certain physiological processes in contrast to others, so that it is possible for the rate of one to be increased with the same exposure that retards another.

SUNLIGHT, X-RAYS AND ELECTRIC LIGHT

Pincussen - 1922 - studied the effect of sunlight, X-rays and intense electric light (1500 candle power) on diabetes

patients and on experimental glycosuria, using in this instance rabbits injected with adrenalin and sensitized to light with eosin and methylene blue. After exposure to the sunlight he found that the carbohydrates are mobilized in the whole body. There is an increase of carbohydrates in the blood stream, where they are oxydized. The carbohydrate output in urine is below the normal.

With electric light, filtered through a water filter to eliminate the effect of heat, the results are the same as with sunlight.

No effect was found on the carbohydrate metabolism after the exposure to X-rays.

CONCLUSION

It is evident, then, that previous work has shown an increased rate of carbon dioxide production in visible light, an increase in calcium and phosphorus metabolism after exposure to ultra violet light, an increased nitrogen output after exposure to X-rays, and an increased nitrogen output and rate of carbon dioxide production after exposure to radium rays.

PART II -- The Action of X-Rays on the Basal Metabolism of Birds.

The experiments consisted, briefly, in measuring the oxygen consumption in canary-birds before and after the exposure to X-rays. In determining the oxygen consumption I used an apparatus designed by Dr. A. L. Meyer, of the School of Hygiene and Public Health, Johns Hopkins University, who will publish a detailed description of the method shortly. It is a very simple method for measuring the metabolism in small animals and it gives very accurate results.

Using this apparatus the oxygen consumption in cubic centimeters is given directly by the readings on a system of two communicating burettes, correction being made for the differences observed in the flask and chamber temperatures and the barometric pressure in the room during the experiment.

In these experiments the oxygen consumption was measured in cubic centimeters per bird for a period of five minutes. Then dividing by the weight of the bird (including feathers) and by the number of minutes, the oxygen consumed in cubic centimeters, per gram of bird, per minute was obtained. Multiplying this figure by 1,000 and then by 60, the oxygen consumption in cubic centimeters per kilogram of bird per hour was calculated. Multiplying this figure by 1.429 (weight of one liter of oxygen) and dividing

by 1000, we have the consumption of oxygen in grams per kilogram of bird per hour.

For each experiment the temperature of the air circulating in the apparatus and the barometric pressure were observed. These results multiplied by the correction factor given by Haldane's Table (page 60) give the numbers of the last column of results: Oxygen consumption in grams per kilogram of bird per hour for normal temperature and pressure.

Six female canary-birds were used, their weight varying from 15 to 17 grams. The following figures give the weight of the different birds, and as some died they were weighed with feathers and without, to see how much the feathers represent of the total weight:

Bird	I	.... 15.60	grams	with	feathers
Bird	II	.... 17.40	"	"	"
Bird	II	.... 12.53	"	without	"
Bird	III	.... 16.73	"	with	"
Bird	III	.... 13.45	"	without	"
Bird	IV	.... 16.33	"	with	"
Bird	IV	.... 11.85	"	without	"
Bird	V	.... 15.16	"	with	"
Bird	VI	.... 14.20	"	"	"

In birds II, III and IV the feathers represented 28 per cent, 19.6 per cent and 27.4 per cent, respectively, of the total weight.

Very little is known about the basal metabolism of birds. Only two papers were found on the subject: One by Regnault and Reiset, published in 1849, and another by Groebbels, in 1920.

Regnault and Reiset studying the metabolism of different species of birds at 19 degrees centigrade, established the following figures:

Hen	10.58, 14.34	grams per kilogram per hour
Duck	18.50, 18.52)	
	14.74, 15.27)	" " " " "
Green-finch ...	13.00	" " " " "
Parrot-finch ..	10.97	" " " " "
Sparrow	9.595	" " " " "

Groebbels carried out a series of experiments on bird metabolism, using the following species:

Buzzard	(Buteo buteo L.)
Cow-parsley ...	(Syrnium aluco L.)
Carrion-crow ..	(Corona corone L.)
Starling	(Sturnus vulgaris L.)
Robin	(Erithacus rubecula L.)
Finch	(Fringilla coelebs L.)
Bullfinch	(Pyrrhula pyrrhula europaea Vieill.)
Canary-bird ...	(Serinus canaria L.)

For the last one, the canary-bird, he gives the following data:

Bird	Weight in Grams	Temperature (Degrees)	Oxygen Milligram 30 Minutes	Calories per Kilogram 24 Hours	Remarks
Male	17	21.5	114	1023	Very quiet
Female	17	22.0	110	1023	" "
Female	17	22.6	106	945	" "
Female	17	23.0	121	1023	" "
Female	17	22.0	122	1023	" "

A strict comparison can scarcely be made of my figure for the normal basal metabolism of the canary and those found by Groebbels. This would require a knowledge of the true body weight. It seems pretty certain that Groebbels did not determine the weight of the bird without feathers, which in my experience constitute about 25 per cent of the total weight.

The rate of respirations and the temperature of the animal chamber, are factors of considerable importance. Except in one or two instances, Groebbels fails to record the number of respirations per minute. On the whole, the temperatures to which the canaries were exposed in my experiments were four to five degrees higher than in Groebbels experiments. It is difficult to state how much a difference of this magnitude would affect the metabolism of a canary; but, in the case of the robin, Groebbels finds that a rise from 19 degrees centigrade to 27 degrees centigrade reduces the metabolism about 20 per cent.

Before the exposure to the action of the X-rays a series of measurements were carried out in order to establish the normal metabolism of birds. The results are as follows:

Number of Experiment	Bird Number	Oxygen Grams per Kilogram per Hour N.T.P.	d Deviation from the Mean	d^2
1	I	8.68	.23	.0529
2	I	9.71	1.26	1.5876
3	I	8.68	.23	.0529
4	I	7.89	.56	.3136
5	I	7.26	1.19	1.4161
6	I	7.34	1.11	1.2321
7	I	7.57	.88	.7744
8	I	7.89	.56	.3136
9	I	8.59	.14	.0196
10	I	9.68	1.23	1.5129
11	I	9.37	.92	.8464
12	I	8.73	.28	.0784
13	II	7.34	1.11	1.2321
14	II	7.18	1.27	1.6129
15	II	6.95	1.50	2.2500
16	II	6.33	2.12	4.4944
17	II	7.10	1.35	1.8225

Number of Experi-ment	Bird Number	Oxygen Grams per Kilogram per Hour N.T.P.	d Deviation from the Mean	d^2
18	III	8.98	.53	.2809
19	III	8.08	.37	.1369
20	III	7.63	.82	.6724
21	III	9.06	.61	.3721
22	III	8.51	.06	.0036
23	IV	7.96	.49	.2401
24	IV	7.11	1.34	1.7956
25	IV	5.86	2.59	6.7081
26	IV	5.86	2.59	6.7081
27	IV	6.39	2.06	4.2436
28	IV	6.00	2.45	6.0025
29	V	9.25	.80	.6400
30	V	9.31	.86	.7396
31	V	7.98	.47	.2209
32	V	8.29	.16	.0256
33	V	9.63	1.18	1.3924
34	V	9.24	.79	.6241
35	V	9.48	1.03	1.0609
36	VI	10.27	1.82	3.3124
37	VI	10.81	2.36	5.5696
38	VI	10.96	2.51	6.3001
39	VI	10.04	1.59	2.5281
40	VI	10.50	2.05	4.2025
41	VI	10.04	1.59	2.5281
42	VI	9.11	.66	.4356
43	VI	9.73	1.28	1.6384
44	VI	9.34	.89	.7921
45	VI	8.73	.28	.0784
		380.44		77.8651

Mean: 8.45

Using the formulas:

$$\sigma = \text{Standard Deviation} = \sqrt{\frac{\Sigma d^2}{N}}$$

$$\text{P.E. Mean} = .67449 \frac{\sigma}{\sqrt{N}}$$

I found for my results:

$$\sigma = \sqrt{\frac{77.8651}{45}} = \sqrt{1.73034} = 1.3154$$

$$\text{P.E. Mean} = .67449 \frac{1.3154}{\sqrt{45}} = \frac{.887224}{\sqrt{45}} = \frac{.887224}{6.708} = .1323$$

$$\text{Mean} = 8.45 \pm .1323$$

After establishing the basal metabolism of the normal birds (i.e. the oxygen consumption per kilogram of bird per hour) before the exposure to X-rays, the birds were exposed, while in the metabolism chamber, to different doses of roentgen rays. The X-rays were obtained with a Coolidge tube operating at a secondary voltage of 55,000 , which corresponds roughly to a $3\frac{1}{2}$ inch spark gap. The distance from the anticathode to the bird was $9\frac{1}{2}$ inches.

In calculating the X-ray dose, Remer and Witherbee's formula for unfiltered radiation was used:

$$\frac{\text{Spark gap x milliamperes x minutes}}{(\text{Distance})^2} = \frac{36}{64} = 1 \text{ Skin Dose.}$$

It is evident from this formula that an exposure of about 15 milliampere minutes at $9\frac{1}{2}$ inches distance, and with a $3\frac{1}{2}$ inch spark gap, will be equivalent to one skin dose.

As the bird was enclosed in a glass metabolism chamber, the formula for unfiltered radiation does not apply accurately, but this method was followed for the two following reasons: It was found better to avoid handling the bird as much as possible, and the ventilation in the metabolism chamber prevented the accumulation of ozone which might, in itself, have affected the metabolism.

Bird I received: April 6 - 2 skin doses (about 30 milliampere-minutes),
April 20 - 2 skin doses,
April 27 - 4 skin doses,

and was observed until May 2nd.

Bird II received: April 8 - 2 skin doses.

April 9 - Bird stands only one one leg; legs very red.

April 10 - Bird died at 3:5 P.M., showing desquamation on the legs, but no apparent lesions on the skin were observed.

Bird III - Died before exposure to X-rays.

Bird IV received:	April 25	- 1 skin dose.
	" 28	- died. No apparent lesion on the skin was observed.
Bird V received:	May 3	- 1/2 skin dose, and was observed until May 14th.
Bird VI received:	May 6	- 4 skin doses and was observed until May 14th.

EXPERIMENTS

Bird Number	Period	Mean	P.E. Mean	X-rays in Skin Doses	Difference from Normal Mean	P.E. Difference	Time of Effect,* Minutes	Per Cent Variation from the Normal Mean
I	Normal	8.45	.1612	–	–	–	–	–
I	April 6 - 10.00 - X-rays							
"	" " - 10.54 -	11.75	.5576	2	+3.30	.5804	54	+39.1
"	April 6 - 11.36 to April 19 -3.30	7.82	.1427	–	- .63	–	–	- 7.5
"	April 20 - 11.38 - X-rays							
"	" " - 12.01	9.95	.4938	2	+1.50	.5194	22	+17.8
"	April 20 - 12.18 to April 26 - 11.13..	7.54	.1185	–	- .91	–	–	-10.8
"	April 27 - 10.40 - X-rays							
"	" " - 12.18	6.39	.4775	4	-2.06	.4775	1 h. 38 m.	-24.4
"	" 28 - 11.46 to May 2 - 12.5.......	7.61	.0827	–	- .84	–	–	- 9.9
II	Normal	6.98	.1051	–	–	–	–	–
"	April 8 - 11.15 - X-rays							
"	" " - 11.32	10.81	.3641	2	+3.83	.3641	17 m.	+54.9
"	April 8 - 11.56 to April 9 - 5.13	7.26	–	–	+ .28	–	–	+ 4.0
IV	Normal	6.58	.2132	–	–	–	–	–
"	April 25 - 10.40 - X-rays							
"	" " - 11.06	8.83	.5221	1	+2.25	.5638	26	+34.2
"	April 25 - 11.40 to April 28 - 1.02	5.76	.1480	–	- .82	–	–	-12.46
V	Normal	9.03	.1488	–	–		–	
"	May 3 - 2.30 - X-rays							
"	" " - 2.56	11.23	.3936	1/2	+2.20	.4207	26	+24.36
"	May 3 - 3.17 to May 14 - 11.14	9.39	.1410	–	+ .36	–	–	+ 4.0
VI	Normal	9.95	.1477	–	–	–	–	–
"	May 6 - 10.35 - X-rays							
"	" " - 10.53	10.88	.4670	4	+ .93	–	18	+ 9.3
"	May 6 - 11.09 to May 14 - 12.08	7.99	.1047	–	-1.96	–	–	-19.7

Conclusions

The experiments show that, after exposure to a moderate dose of X-rays, there is a marked, though short-lasting, increase in the rate of oxygen consumption. For a dose of 1/2 a skin dose unit this increase amounted to 24.36 per cent of the normal oxygen consumption, for one skin dose there was an increase of 34.2 per cent, and for two skin doses there was an increase of 47 per cent (average for Bird I dose I and Bird II dose I). A second radiation of two skin doses on the same bird resulted in a smaller increase of 17.8 per cent (Bird I dose II). The increase always came on immediately after exposure and the metabolism returned to normal in about an hour. After this short period of stimulation the average metabolism was lower than it had been before radiation, except in the case of 1/2 skin dose. The bird that had one skin dose showed an average depression of 12.46 per cent for three days after the initial stimulation. Bird I, after its first radiation of two skin doses, showed a depression averaging 7.5 per cent over a period of two weeks, after its second dose it showed an average depression of 10.8 per cent for a week, and after its third dose, which amounted to four skin doses, there was no initial stimulation at all. The immediate effect was a depression of 24.4 per cent and the next

day the metabolism was nearly normal but showed an average depression of 9.9 per cent for several days.

This bird was not observed any further so that it is not known how long the depression lasted. A new bird, given four skin doses, showed a small rise of 9.3 per cent, followed by a gradual and steady fall which gave an average decrease in metabolism of 19.7 for a week.

Further work on other animals and with X-rays of different penetrations should be made, but the results with canaries exposed to soft X-rays lead one to the following conclusions: A dose of 1/2 a skin unit gives a small stimulation with no subsequent depression. Doses of one to two skin units give a marked temporary stimulation, followed by a slight depression which lasts for a week or more. A dose of four skin units may give a small initial rise but the depression is more marked, amounting to about a 20 per cent decrease in basal metabolism which may extend over a period of a week or more.

These results fall in with the well-known fact that small doses of X-rays are in general stimulating, whereas large doses are injurious.

BIRD NO. I
BEFORE EXPOSURE TO X-RAYS

Date		Bird	Time	Flask Tempera-ture	Baro-metric Pres-sure	Respi-rations per Minute	Chamber Temper-ature	Oxygen in C.C. Five Minutes per Bird	Oxygen in C.C. per Gram of Bird per Min. N.T.P.	Grams of Oxygen per Kilogram per Hour
March	30	Quiet	11.15	21.20	30.42	120	26.5	8.6	.101	8.68
"	"	"	11.45	21.55	30.41	120	26.0	9.6	.113	9.71
"	"	Moved	11.56	21.70	30.41	112	25.5	8.6	.101	8.68
"	"	Quiet	12.36	22.00	30.40	---	25.5	7.8	.092	7.89
"	31	"	12.12	21.50	30.05	140	25.0	7.3	.086	7.26
"	31	Moved	12.30	21.65	30.05	136	25.5	7.4	.086	7.34
"	31	Quiet	12.54	21.95	30.04	132	26.0	7.6	.088	7.57
April	4	"	9.56	21.50	30.15	132	27.0	7.9	.092	7.89
"	"	"	10.19	21.65	30.15	116	26.5	8.6	.100	8.59
"	"	"	11.22	22.65	30.15	132	26.5	9.7	.113	9.68
"	"	Moved	11.46	22.60	30.15	132	27.0	9.4	.109	9.37
"	"	Quiet	12.22	22.95	30.15	128	26.5	8.8	.102	8.75
April	6	-----	10.00	-- X-Rays: Two Skin Doses.						
"	"	Quiet	10.21	21.10	30.40	164	25.5	12.2	.144	12.31
"	"	"	10.54	21.35	30.40	140	25.5	11.3	.133	11.45
"	"	"	11.36	21.70	30.39	128	26.0	8.0	.094	8.06
"	"	Moved	12.6	21.85	30.38	120	25.5	8.1	.095	8.13
"	7	Quiet	1.11	22.55	30.16	132	26.0	8.0	.093	7.96
"	"	Moved	1.37	22.90	30.15	120	26.0	8.5	.099	8.52
"	9	"	3.18	25.40	29.81	128	27.5	7.0	.079	6.80
"	"	Quiet	3.40	25.55	29.81	128	28.0	7.1	.079	6.80

BIRD NO. I - CONT.

Date		Bird	Time	Flask Tempera- ture	Baro- metric Pres- sure	Respi- rations per Minute	Chamber Temper- ature	Oxygen in C.C. Five Minutes per Bird	Oxygen in C.C. per Gram of Bird per Min. N.T.P.	Grams of Oxygen per Kilogram per Hour
April	11	Quiet	10.3	26.10	29.55	148	28.5	8.0	.089	7.70
"	"	Moved	10.54	26.25	29.53	144	28.0	7.1	.079	6.80
"	12	"	1.54	22.55	29.65	156	26.0	7.6	.087	7.49
"	"	Quiet	2.32	22.95	29.66	140	26.5	7.9	.090	7.71
"	19	"	2.56	22.70	30.25	136	25.5	9.0	.105	8.98
"	"	"	3.30	23.10	30.24	132	25.0	8.9	.104	8.90
April	20	--	11.38	-- X-RAYS:	Two Skin Doses					
"	20	Quiet	12.1	23.05	30.17	152	26.5	10.9	.126	10.81
"	"	"	12.18	23.10	30.16	132	26.0	9.0	.104	8.89
"	"	Moved	12.38	23.20	30.16	128	26.5	7.9	.091	7.50
"	21	"	11.36	23.10	30.32	120	26.5	7.9	.092	7.89
"	"	Quiet	12.1	23.30	30.30	120	26.5	7.1	.082	7.03
"	"	"	12.22	23.30	30.29	120	26.8	7.4	.086	7.34
"	22	"	10.40	22.55	30.32	120	26.0	7.4	.086	7.34
"	"	"	11.9	22.75	30.31	112	26.0	6.8	.079	6.79
"	"	"	11.37	22.85	30.30	112	25.5	6.4	.075	6.40
"	24	"	11.38	22.25	30.52	128	25.0	8.7	.105	8.84
"	"	Moved	11.59	22.50	30.52	112	25.5	8.0	.094	8.01
"	"	Quiet	12.26	22.75	30.50	108	25.5	7.9	.093	7.79
"	26	"	10.43	22.55	30.06	128	25.0	7.9	.091	7.80
"	"	"	11.15	22.70	30.06	112	25.5	7.6	.087	7.49

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BIRD NO. I - CONC.

Date		Bird	Time	Flask Tempera-ture	Baro-metric Pres-sure	Respi-rations per Minute	Chamber Temper-ature	Oxygen in C.C. Five Minutes per Bird	Oxygen in C.C. per Gram of Bird per Min. N.T.P.	Grams of Oxygen per Kilogram per Hour
April	27	--	10.40	---	X-RAYS :	Four Skin Doses				
April	27	Quiet	11.05	22.65	30.07	124	25.0	7.2	.083	7.10
"	"	"	11.30	22.70	30.07	120	25.0	6.7	.077	6.64
"	"	Moved	11.54	22.80	30.07	120	25.5	6.4	.074	6.34
"	"	Quiet	12.18	22.85	30.07	118	25.5	5.5	.064	5.48
"	28	"	11.46	22.15	30.23	128	27.5	7.9	.092	7.59
"	"	"	12.5	22.20	30.22	116	28.0	7.3	.085	7.26
"	"	"	12.25	22.20	30.22	124	27.0	7.5	.087	7.50
"	29	Moved	11.13	21.80	30.30	136	25.0	8.2	.096	8.20
"	"	Quiet	11.34	21.90	30.29	128	26.0	7.9	.092	7.89
"	"	"	11.53	22.00	30.29	116	26.5	6.9	.080	6.87
May	2	"	11.6	21.90	30.38	123	27.0	8.0	.094	8.05
"	"	Moved	11.26	22.05	30.38	120	26.5	7.5	.088	7.58
"	"	Quiet	11.45	22.15	30.37	120	25.0	7.5	.088	7.58
"	"	"	12.5	22.25	30.37	116	26.5	7.2	.085	7.26

BIRD NO. II - BEFORE EXPOSURE TO X-RAYS

Date	Bird	Time	Flask Tempera-ture	Baro-metric Pres-sure	Respi-rations per Minute	Chamber Temper-ature	Oxygen in C.C. Five Minutes per Bird	Oxygen in C.C. per Gram of Bird per Min. N.T.P.	Grams of Oxygen per Kilogram per Hour
April 6	Quiet	3.13	23.85	30.35	132	25.5	8.2	.086	7.34
" "	"	3.31	24.10	30.34	120	25.0	8.0	.084	7.18
" "	Moved	3.54	24.25	30.34	112	25.0	7.8	.081	6.95
" 8	Quiet	9.54	24.25	29.98	116	25.5	7.1	.074	6.55
" "	"	10.13	24.40	29.98	120	25.0	8.0	.083	7.10
April 8	---	11.15	X-RAYS: Two Skin Doses						
April 8	Quiet	11.32	24.70	29.99	152	26.5	12.2	.126	10.81
" "	"	11.56	24.80	29.99	112	27.0	7.6	.078	6.71
" 9	"	4.51	25.35	29.81	116	27.5	7.1	.073	6.26
" "	Moved	5.13	25.90	29.81	116	28.0	7.4	.076	6.49

April 10 - Died

BIRD NO. III - BEFORE EXPOSURE TO X-RAYS

Date	Bird	Time	Flask Tempera-ture	Baro-metric Pres-sure	Respi-rations per Minute	Chamber Temper-ature	Oxygen in C.C. Five Minutes per Bird	Oxygen in C.C. per Gram of Bird per Min. N.T.P.	Grams of Oxygen per Kilogram per Hour
April 11	Moved	2.23	26.50	29.40	143	26.0	9.9	.105	8.98
April 11	Quiet	2.42	26.55	29.38	144	25.5	8.9	.094	8.08
April 11	"	3.2	26.55	29.38	140	26.0	8.4	.089	7.63
April 19	Moved	4.32	23.20	30.23	132	25.0	9.7	.106	9.06
April 19	Quiet	4.56	23.30	30.22	128	25.5	9.1	.099	8.51

Died before exposure to X-rays.

BIRD NO. IV- BEFORE EXPOSURE TO X-RAYS

Date		Bird	Time	Flask Tempera-ture	Baro-metric Pres-sure	Respi-rations per Minute	Chamber Temper-ature	Oxygen in C.C. Five Minutes per Bird	Oxygen in C.C. per Gram of Bird per Min. N.T.P.	Grams of Oxygen per Kilogram per Hour
April	21	Quiet	12.46	23.25	30.28	140	26.0	8.3	.093	7.96
"	"	"	1.13	23.40	30.28	120	25.5	7.4	.083	7.11
"	22	"	12.25	23.00	30.30	108	25.0	6.1	.068	5.36
"	"	"	12.49	23.15	30.29	108	25.5	6.1	.068	5.36
"	24	Moved	12.48	22.90	30.50	124	25.0	6.6	.075	6.39
"	"	Quiet	1.8	23.00	30.49	116	26.0	6.2	.070	6.00
April	25	--	10.40	-- X-RAYS:	One Skin Dose					
April	25	Quiet	11.06	22.55	30.33	148	25.5	9.2	.103	8.83
"	25	"	11.40	22.65	30.32	140	25.5	7.6	.085	7.26
"	"	"	12.9	22.80	30.30	112	25.0	6.1	.068	5.86
"	26	Moved	11.43	22.85	30.04	112	25.0	5.9	.065	5.56
"	"	Quiet	12.03	23.00	30.04	108	25.5	5.9	.065	5.56
"	"	"	12.22	23.05	30.04	116	26.0	6.4	.071	6.1[illegible]
"	27	"	12.46	22.85	30.07	120	25.0	6.0	.067	5.72
"	"	"	1.3	23.00	30.06	120	25.5	6.1	.068	5.39
"	28	"	12.43	22.35	30.22	128	26.0	4.9	.055	4.69
"	28	"	1.2	22.45	30.22	132	25.5	5.5	.061	5.23

April 28 -- 5.00 Bird Died.

BIRD NO. V - BEFORE EXPOSURE TO X-RAYS

Date		Bird	Time	Flask Tempera-ture	Baro-metric Pres-sure	Respi-rations per Minute	Chamber Temper-ature	Oxygen in C.C. Five Minutes per Bird	Oxygen in C.C. per Gram of Bird per Min. N.T.P.	Grams of Oxygen per Kilogram per Hour
May	1	Quiet	12.5	21.85	30.49	132	26.0	8.9	.103	9.25
"	"	"	12.23	21.95	30.49	132	26.0	9.0	.109	9.31
"	"	"	12.44	22.10	30.48	124	25.5	7.7	.093	7.98
"	"	Moved	1.3	22.15	30.48	128	25.5	8.0	.097	8.29
"	2	Quiet	10.13	21.55	30.39	132	24.5	9.3	.112	9.63
"	"	"	10.33	21.70	30.39	124	24.5	8.9	.108	8.94
"	"	Moved	10.53	21.80	30.38	128	25.0	9.1	.110	9.48
May	3	--	2.30	-- X-RAYS: 1/2 Skin Dose						
May	3	Quiet	2.56	21.45	30.12	140	28.5	11.2	.134	11.23
"	"	"	3.17	21.60	30.11	132	28.0	9.9	.118	10.15
"	"	Moved	3.37	21.80	30.11	128	28.5	9.9	.118	10.15
"	"	"	3.57	21.95	30.10	128	28.0	10.0	.120	10.32
"	4	"	2.30	21.95	29.84	128	24.0	10.1	.120	10.27
"	"	Quiet	2.48	22.15	29.83	120	24.5	9.7	.115	9.68
"	"	"	3.4	22.35	29.83	116	24.5	9.5	.113	9.73
"	5	"	2.7	22.00	29.75	124	25.5	8.7	.103	8.80
"	"	Moved	2.25	22.20	29.74	136	26.0	10.1	.120	10.27
"	"	Quiet	2.42	22.35	29.74	124	26.0	9.8	.116	9.96
"	7	"	10.20	21.25	29.92	132	25.5	9.7	.116	9.99
"	7	"	10.41	21.35	29.92	128	25.0	9.2	.110	9.45
"	"	"	11.00	21.50	29.92	128	25.0	9.0	.107	9.21
"	8	Moved	3.43	21.95	30.12	124	24.5	7.0	.088	7.18
"	"	"	4.6	21.95	30.10	128	25.0	8.2	.098	8.44
"	"	Quiet	4.30	22.10	30.10	120	25.5	7.5	.089	[illegible]
"	14	Moved	10.33	21.30	29.85	130	25.0	9.4	.112	9.58
"	"	Quiet	10.53	21.55	29.85	130	25.5	8.9	.105	9.04
"	"	"	11.14	21.60	29.85	120	25.5	8.8	.104	8.96

BIRD NO. VI - BEFORE EXPOSURE TO X-RAYS

Date	Bird	Time	Flask Temperature	Barometric Pressure	Respirations per Minute	Chamber Temperature	Oxygen in C.C. Five Minutes per Bird	Oxygen in C.C. per Gram of Bird per Min. N.T.P.	Grams of Oxygen per Kilogram per Hour
May 4	Quiet	3.24	22.55	29.82	128	26.0	10.1	.120	10.27
" "	Moved	3.42	22.65	29.82	136	25.5	10.6	.126	10.51
" "	"	4.00	22.65	29.81	136	26.0	10.8	.128	10.96
" 5	Quiet	2.58	22.40	29.74	140	26.0	9.9	.117	10.04
" "	Moved	3.14	22.50	29.74	144	26.5	10.3	.122	10.50
" "	"	3.31	22.65	29.74	140	26.0	9.9	.117	10.04
" "	Quiet	3.47	22.75	29.71	132	26.5	9.0	.106	9.11
" "	Moved	4.6	22.80	29.71	140	26.0	9.6	.113	9.73
" "	Quiet	4.23	22.80	29.71	132	26.5	9.1	.109	9.34
" "	Very Quiet	4.43	22.95	29.71	120	26.5	8.6	.102	8.73
May 6	--	10.35	X-RAYS: Four skin doses						
May 6	Moved	10.53	21.95	29.84	144	24.5	11.5	.136	11.66
" 6	Quiet	11.9	22.10	29.84	132	25.0	11.3	.134	10.78
" "	"	11.26	22.10	29.84	128	25.0	10.0	.119	10.20
" "	"	11.43	22.20	29.83	124	25.0	8.5	.101	8.05
" "	"	12.2	22.30	29.82	116	25.0	7.7	.091	7.80
" "	"	12.19	22.35	29.82	116	25.5	7.5	.08[illegible]	7.04
" 7	"	11.10	21.60	29.91	128	25.0	8.2	.097	8.34
" "	Moved	11.31	21.65	29.91	130	25.5	8.6	.102	8.73
" "	Quiet	11.53	21.75	29.91	128	25.5	8.0	.095	8.11
" "	"	12.13	21.90	29.91	124	25.5	7.7	.091	7.80
" 8	"	4.49	22.05	30.10	132	25.0	7.9	.095	8.12
" "	Moved	5.4	22.15	30.10	136	25.0	8.4	.101	8.66
" "	Quiet	5.23	22.20	30.10	132	25.5	8.2	.09[illegible]	8.44
" 14	"	11.25	21.60	29.86	132	26.0	7.4	.087	7.4[illegible]
" "	Moved	11.47	21.75	29.86	132	26.5	7.2	.085	7.34
" "	Quiet	12.3	21.35	29.36	128	26.0	6.[illegible]	.079	6.[illegible]

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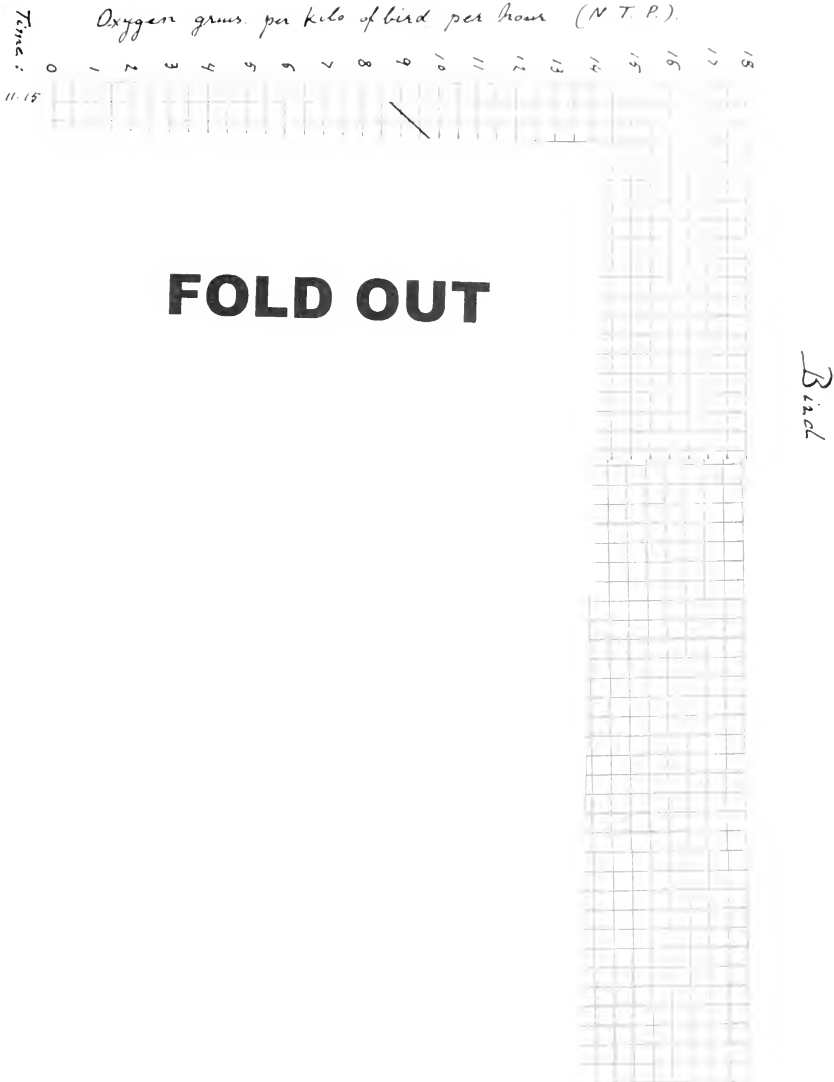
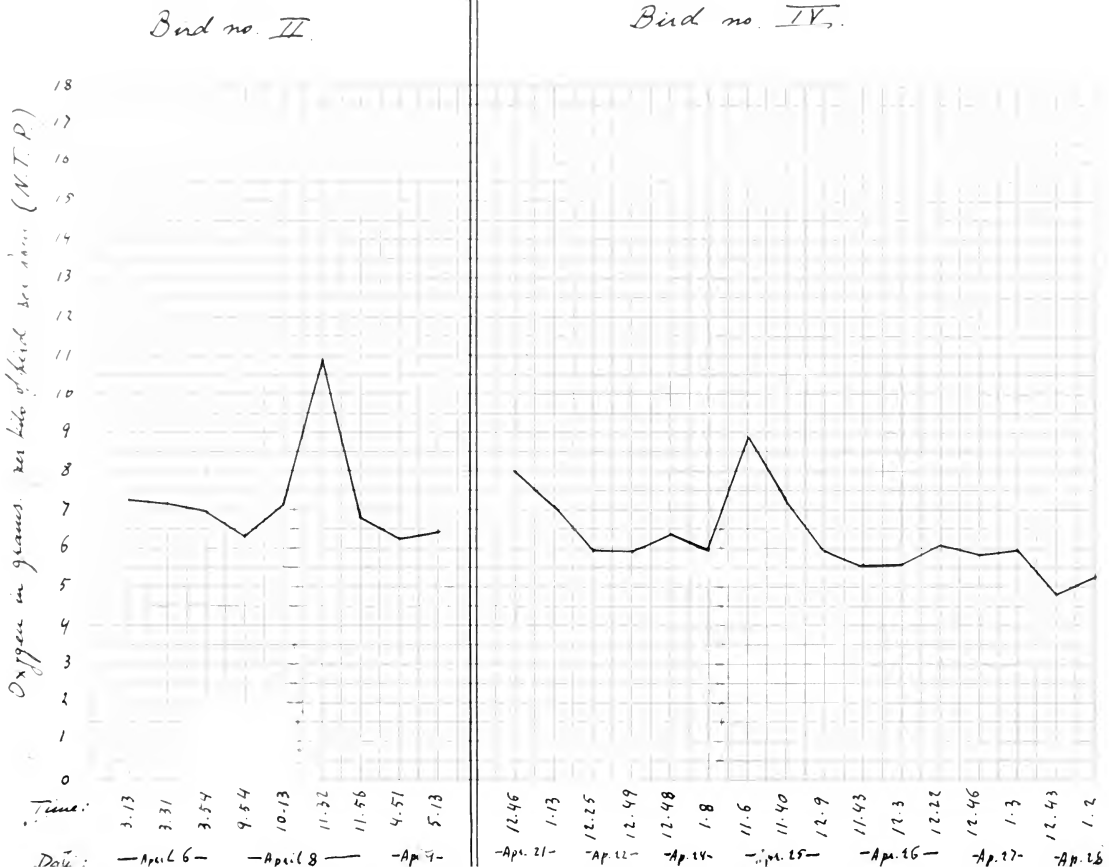
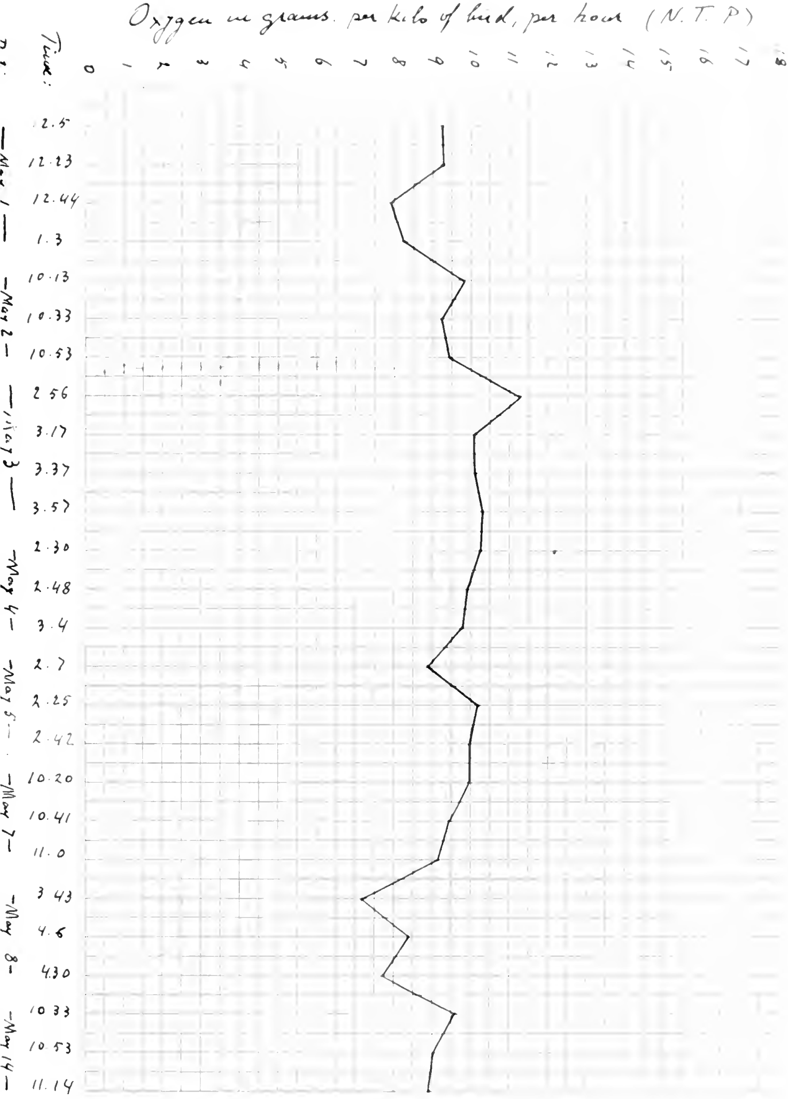
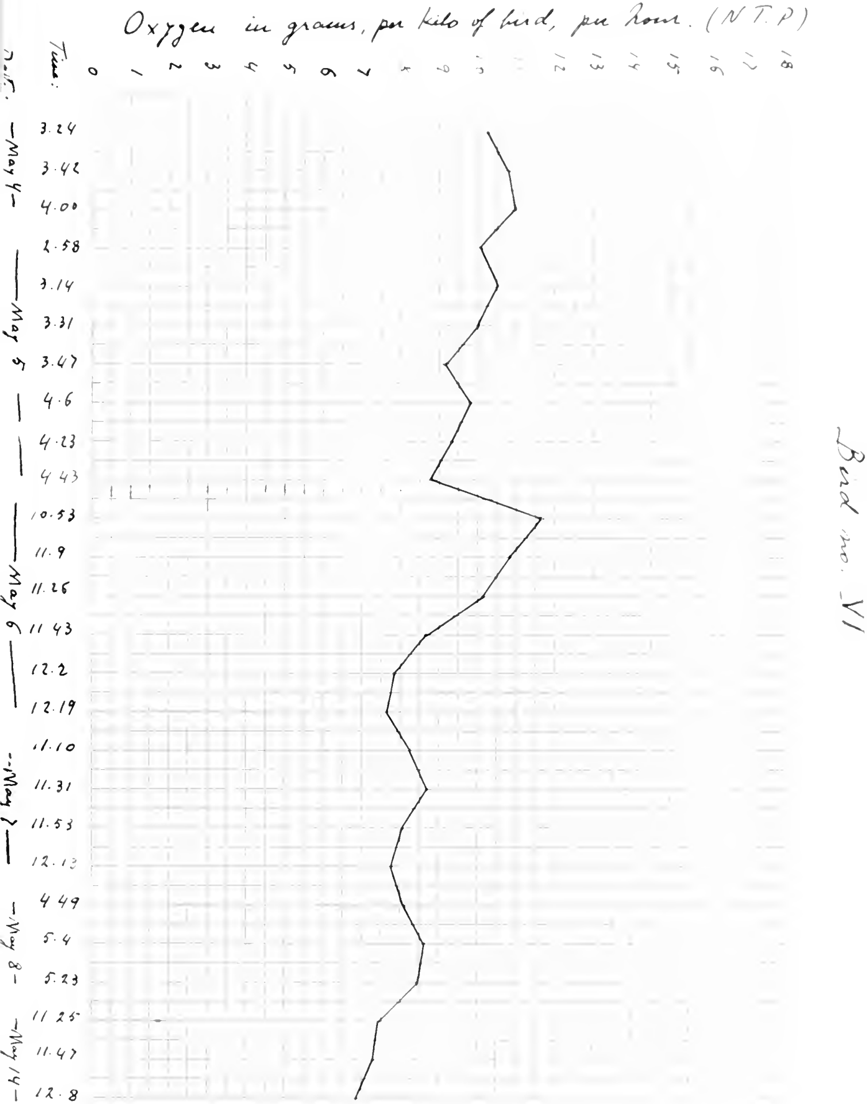

Oxygen grms. per kilo of bird per hour (N. T. P.).
Time:
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
11.15
Bird

FOLD OUT


Bird no. II
Bird no. IV.
Oxygen in grams per kilo of bird per hour (N.T.P.)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Time:
3.13
3.31
3.54
9.54
10.13
11.32
11.56
4.51
5.13
12.46
1.13
12.25
12.49
12.48
1.8
11.6
11.40
12.9
11.43
12.3
12.22
12.46
1.3
12.43
1.2
Date:
April 6
April 8
Ap. 21
Ap. 22
Ap. 24
Ap. 26
Ap. 27
Ap. 28


Oxygen in grams. per kilo of bird, per hour (N.T.P)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Time:
12.5
12.23
12.44
1.3
10.13
10.33
10.53
2 56
3.17
3.37
3.57
2.30
2.48
3.4
2.7
2.25
2.42
10.20
10.41
11.0
3 43
4.6
4.30
10 33
10.53
11.14
May 1
May 2
May 3
May 4
May 5
May 7
May 8
May 14

Bird no V



Oxygen in grams, per kilo of bird, per hour. (N.T.P.)
Time:
Date.
0
1
2
3
4
5
6
7
12
13
14
15
16
17
18
3.24
3.42
4.00
2.58
3.14
3.31
3.47
4.6
4.23
4.43
10.53
11.9
11.26
11.43
12.2
12.19
11.10
11.31
11.53
12.13
4.49
5.4
5.23
11.25
11.47
12.8
May 4
May 5
May 6
May 7
May 8
May 14
Bird no. VI